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The CMS inner Tracker Endcap PiXel upgrade

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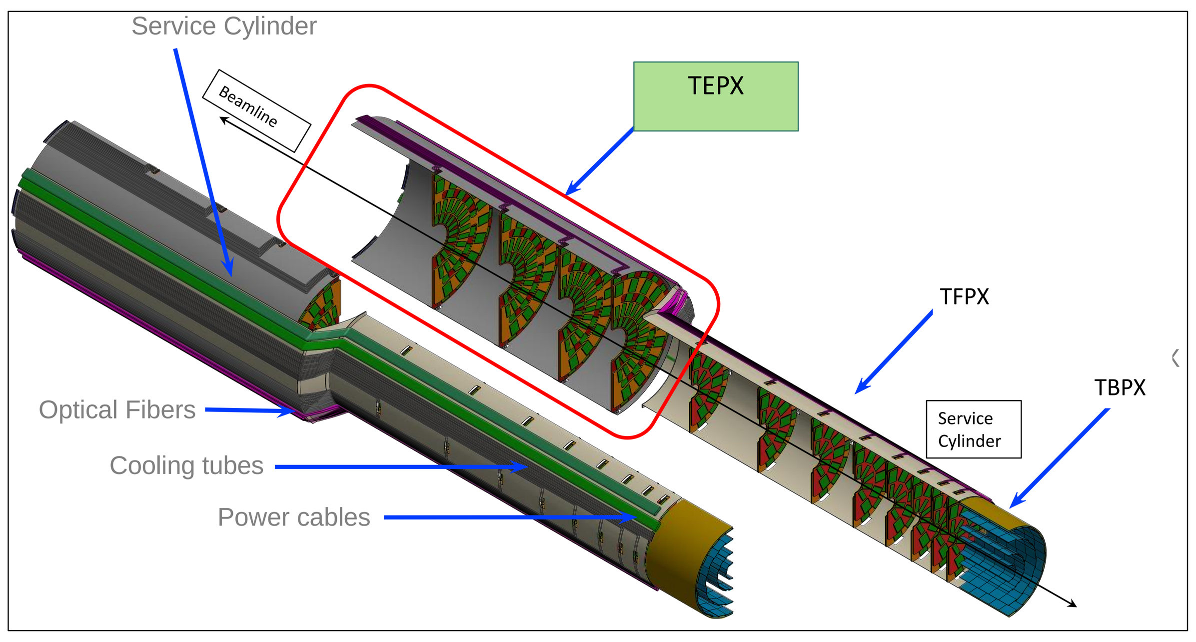
Introduction

- The **High Luminosity Large Hadron Collider** (HL-LHC) at CERN is expected to collide protons at a centre-of-mass energy of 14 TeV and to reach the unprecedented peak instantaneous luminosity of 7x$10^{34}cm^{-2}s^{-1}$ with an average number of pileup events of 200
- **CMS** and ATLAS experiments will be collecting up to 4000 fb^{-1} during the project's lifetime

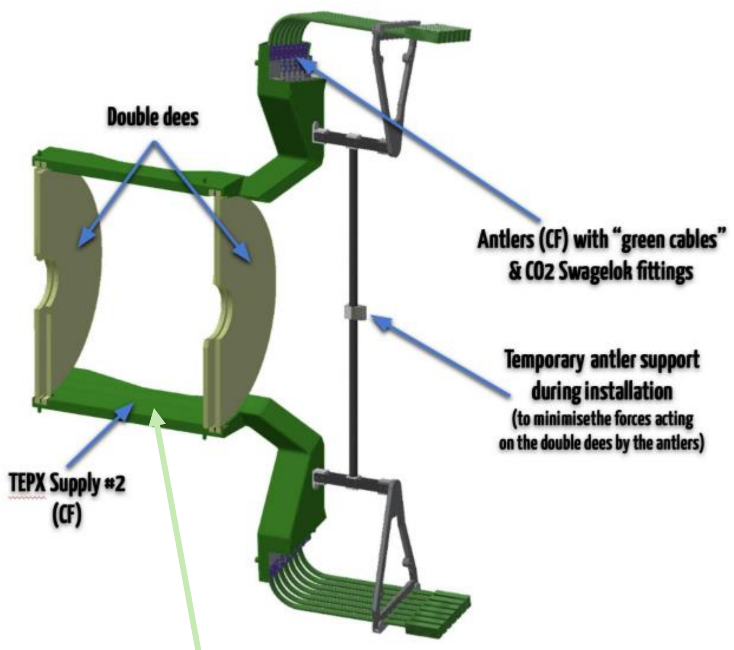


CMS inner tracker layout of the phase 2 upgrade

- To account for this extreme scenario, the **CMS detector** will be substantially **upgraded** before the start of the HL-LHC
- The **CMS silicon pixel detector** will be replaced, and the new detector will feature increased radiation hardness, higher granularity, capability to handle higher data rate and longer trigger latency
  - **TEPX** features custom materials, designs and modules to tackle the demanding challenges
- Timeline:
  - Prototyping of TEPX dee structures expected to finish by the end of the year
  - Final assembly completed by 2027

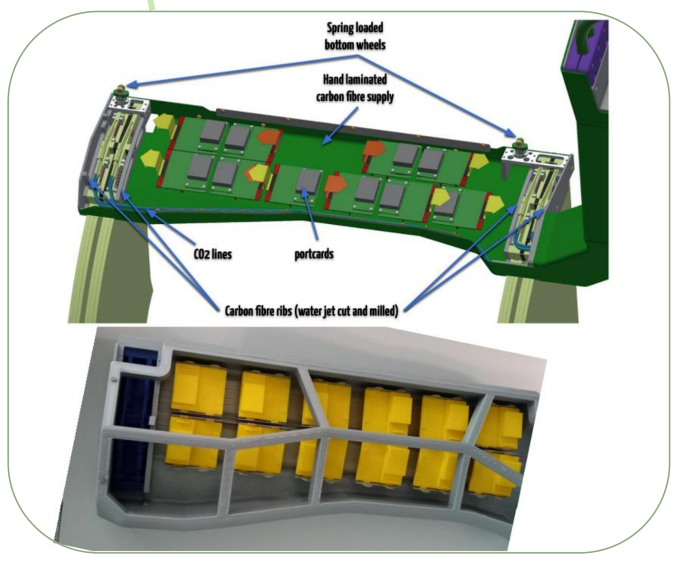
TEPX design

- **4 TEPX structures** per end of the detector resulting in a total of 16 double dees in the whole detector
- Whole structure cooled by cooling tubes with **mixed phase CO_2** provided by a central cooling plant
  - Expected coolant temperature when operating is $-35°C$
  - Smaller temperature gradient along the cooling tubes
  - Great cooling performance

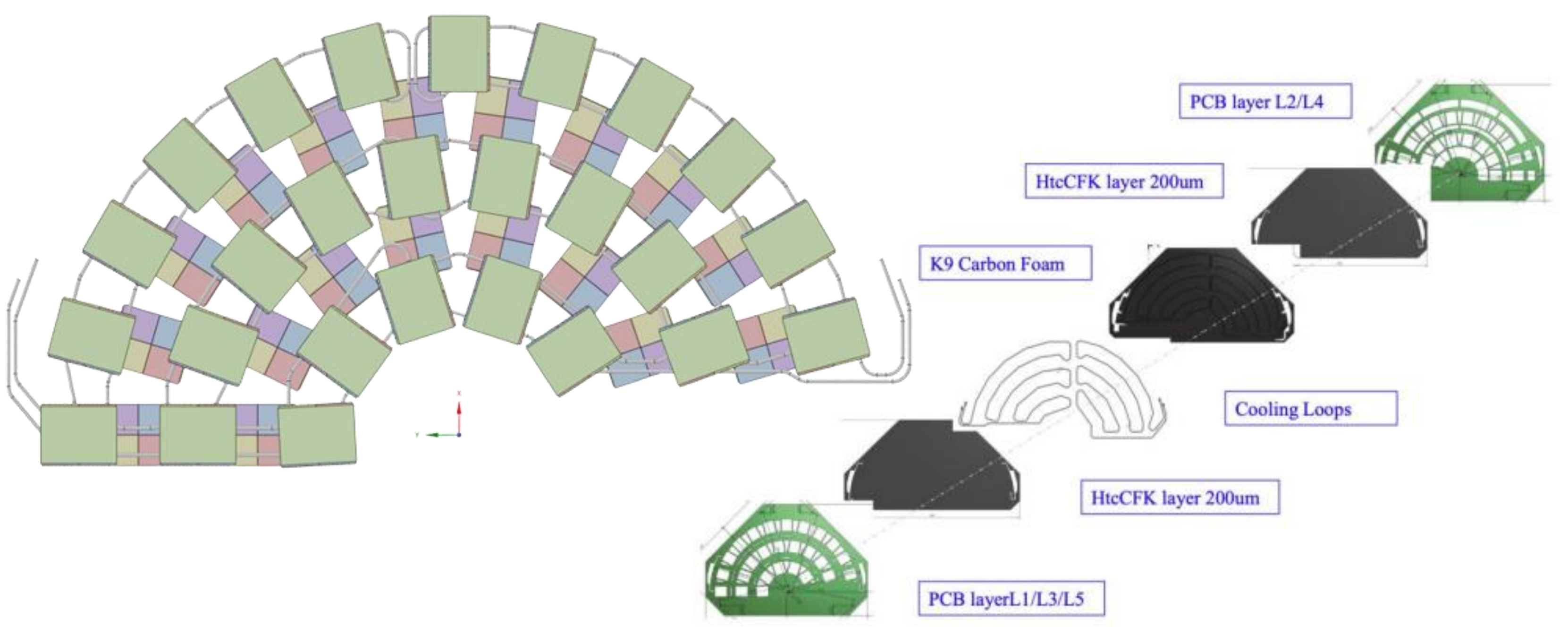


Disks and supply tubes

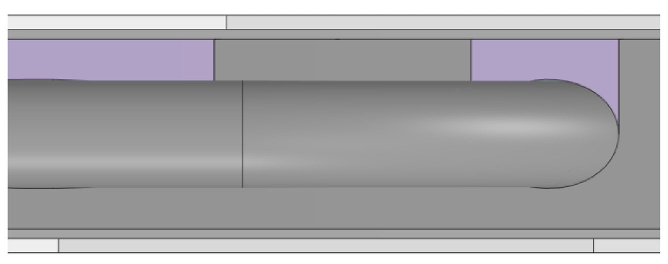
- TEPX features **4 double dees** per quadrant
  - Split into two structures
- Modules connected to a PCB that carries power and data
  - Connectors at the edges carry signals to supply tubes
- **Portcards** installed on the supply tubes

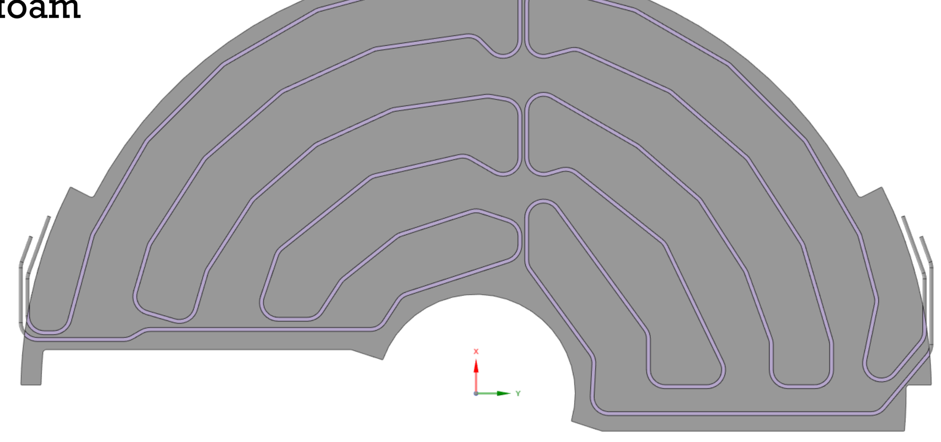


Dee layout

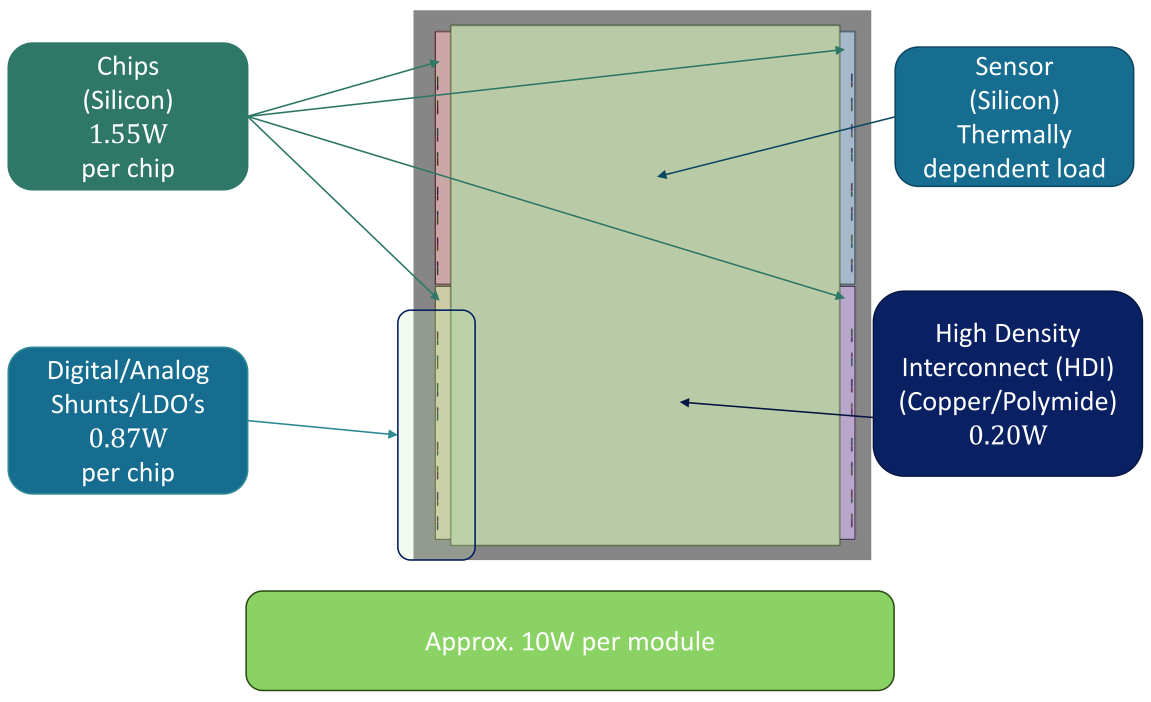


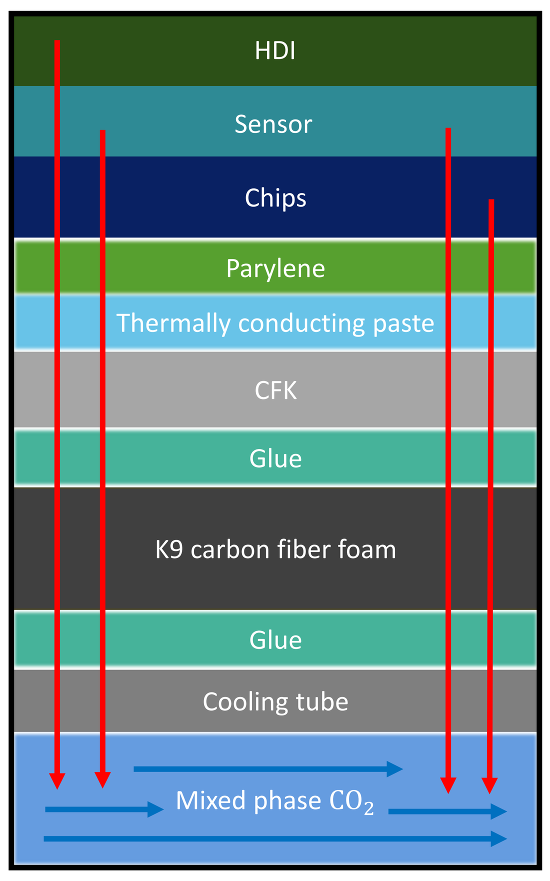
- Each dee fits a total of **44 modules** arranged in **5 concentric rings**
  - Rings 1,3 and 5 on one side and ring 2 and 4 on the other side
- Currently planned to coat the modules in a thin **parylene** layer to insulate read-out chip from sensor and chip backside from CF of the dee
- Use custom lightweight high thermal conductivity materials for the dees
- Considering making the cooling tubes out of **titanium** instead of **stainless steel**
  - Approximately double the radiation length and half the density of stainless steel
- **Trench** carved out of the K9 **Carbon Foam** that is later filled with a glue-carbon-foam mixture has been found as the optimal way to integrate the **cooling tubes** into the foam





Cooling and power consumption





Path of the heat

- Each of the 44 **modules** consists of
  - **4 chips** with 4 digital/analog Shunts/LDOs each
  - **1 Sensor** with temperature dependent thermal load
  - 1 High Density Interconnect (**HDI**)
- Use of **dopants in glue and thermal paste** to significantly increase their thermal conductivity

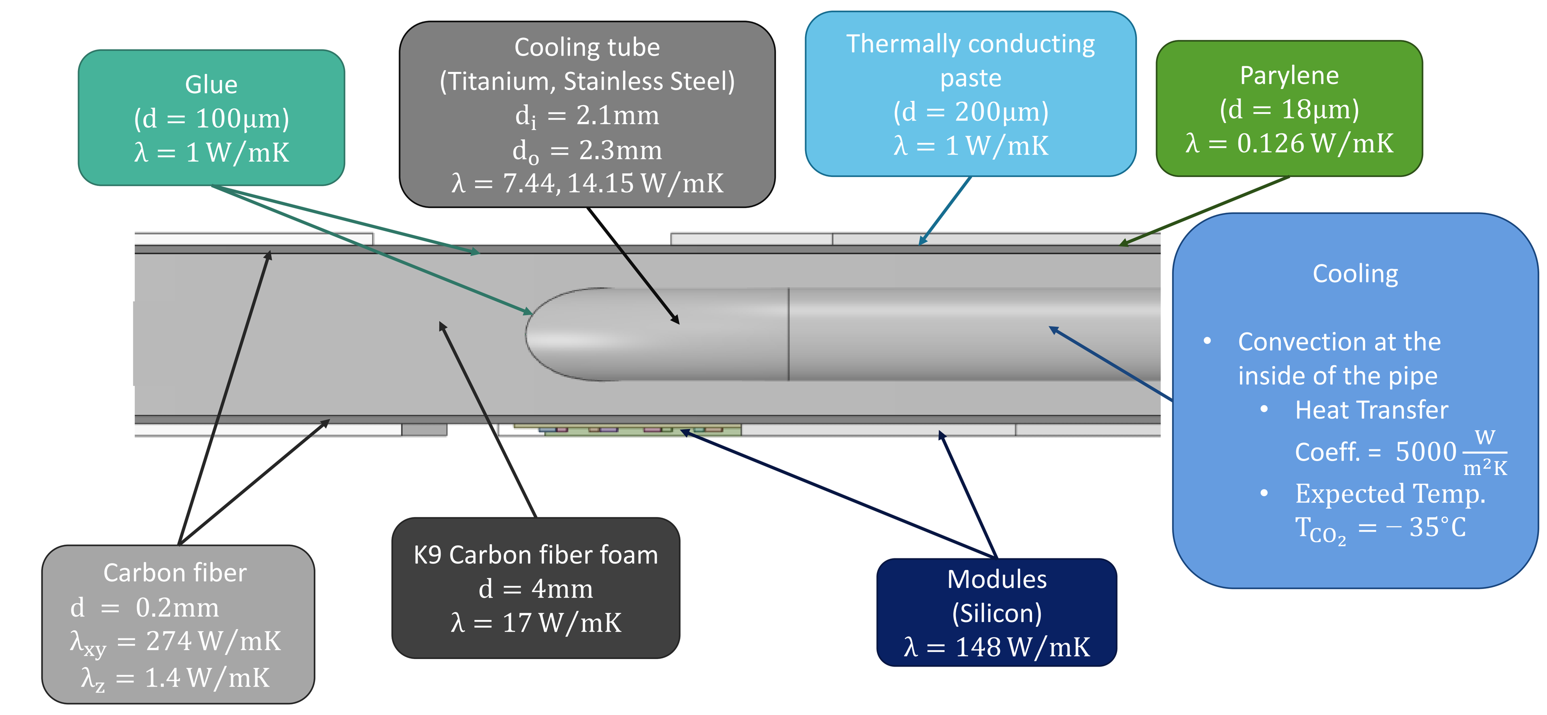
Thermal runaway

- **Leakage current** in sensor grows with temperature, increasing the power dissipation
  - Increasing the temperature if the heat cannot be absorbed completely by the cooling system resulting in a **loss of thermal stability**

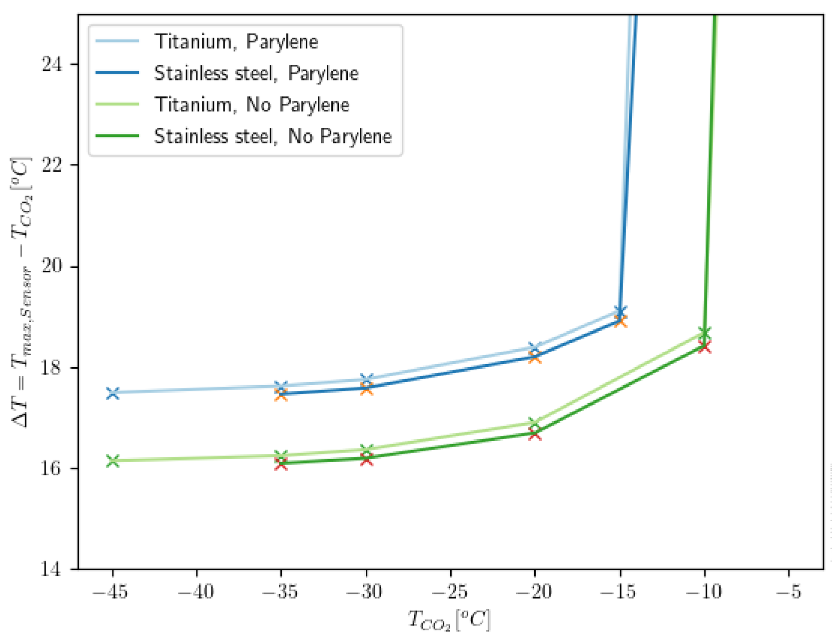
$$P(T) = U_{bias} * \Phi(r) * \alpha_0 * V * \left(\frac{T^2}{T_0^2}\right) * \exp\left(C\frac{T - T_0}{TT_0}\right)$$

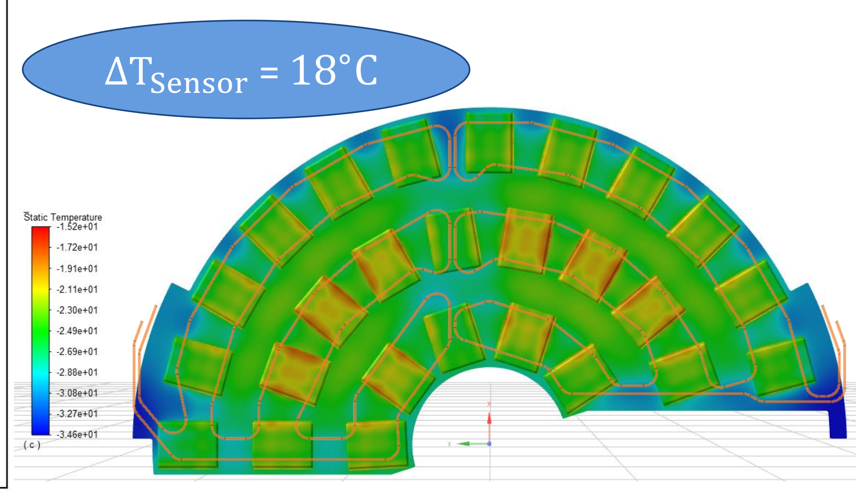
A critical temperature at which the sensors will overheat exists

Finite element analysis



- Simulation of **full dee**
- **Safe margin to thermal runaway** at CO_2 operating temperature of - 35°C assuming a conservative scenario
- **Parylene** coating to the modules results in a + 2°C increase
- **Titanium tubes** decrease the mass by half of the cooling tubes maintaining same thermal performance





Summary

- **Inner pixel tracker endcap upgrade** was presented, as part of the inner tracker phase-2 upgrade
  - Upgrade will feature increased radiation hardness, higher granularity, capability to handle higher data rate and longer trigger latency
  - The **FEA simulations** point to the TEPX design providing **sufficient cooling** to the modules to avoid thermal runaway in the sensors
- First working **prototype** ready to be tested and compared to the FEA results